MINERAL AND ELECTROLYTE RESPONSES FOLLOWING SEVERE DECOMPRESSION STRESS

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SUMMARY PAGE

THE PROBLEM

To evaluate the influence of pressure and decompression on mineral metabolism, distribution, or loss in animals. The animal model may then serve to better understand the effect of diving schedules and routines in man.

FINDINGS

Mineral and electrolyte changes in serum and urine of rats during the first hour and after 1 day following severe decompression appear to result from an adrenal cortical response to the dysbaric stress. Following a generalized rebound effect and subsequent returning toward control values, a second period of shifts occurs 3-5 days post-dive. Of particular interest is the concurrent decreases in both serum and urinary calcium.

APPLICATION

While blood and urinary mineral and electrolyte changes have been reported to occur during exposure to pressure and decompression, alterations in mineral and electrolyte distribution for several days following decompression have, to our knowledge, not been observed. Since decompression injury, with or without frank bends, may have longer biochemical consequences than hitherto considered, it is recommended that divers be allowed sufficient time to recover from possible pressure or decompression injury prior to further diving.

ADMINISTRATIVE INFORMATION

This investigation was conducted as part of Bureau of Medicine and Surgery Research Work Unit MF51.524.014-9016BA9K. The present report is Number one on this work unit. It was submitted for review on 25 April 1973, approved for publication on 3 May 1973 and designated as NavSubMedRschLab Report No. 743.

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ABSTRACT

Blood and urinary minerals and electrolytes, and urinary hydroxyproline from adult male rats were measured for periods up to five days following compression and severe decompression, (neither explosive, resulting in 100% mortality, nor "completely safe", giving no symptoms). During the first hour after acute decompression stress, serum ionized calcium and inorganic phosphorus increased and sodium decreased. Within one day, ionized calcium, as well as total calcium, decreased and continued to do so throughout the three-day post-dive study period. Serum sodium returned to control levels by the third day whereas inorganic phosphorus, which had returned toward control levels during post-dive days one and two, experienced a second rise at the end of three days. No significant changes occurred in serum potassium or chloride.

Total urinary excretion of sodium, potassium, calcium, phosphorus and hydroxyproline became depressed below control values one day following severe decompression. This period was followed by a general rebound effect by the third day post-dive. By the fifth day, calcium and hydroxyproline again fell while sodium excretion continued to increase.

The one-hour-serum and one-day-urinary mineral and electrolyte changes resulting from severe decompression are interpreted as adrenal cortical responses to the dysbaric stress and reflect a post-stress hemoconcentration. The subsequent mineral and electrolyte changes away from control values seem to represent rebound effects resulting from the interaction of recurring hemoconcentration episodes and the tendency of metabolic processes to move toward an equilibrium. These findings reinforce observations that several days are required for the re-establishment of homeostasis following decompression stress.

MINERAL AND ELECTROLYTE RESPONSES FOLLOWING SEVERE DECOMPRESSION STRESS

INTRODUCTION

Numerous reports have appeared indicating alterations in blood and urinary electrolytes during periods spent under increased pressure and during decompression. During dives to 10 ATA with men breathing air, Radomski and Bennett[16] found marked decreases in urinary sodium and calcium excretion, correlated with depth, which were completely reversible during decompression. These authors also reported increases in serum potassium and inorganic phosphorus at depth. Immediately following decompression, however, serum potassium, inorganic phosphorus and calcium showed no change from normal levels[12,16].

Philp et al[12] observed that in those divers who developed symptomatic bends, there was a decrease in serum sodium. In other studies, Barthelemy[3] observed a significant decrease in plasma sodium during an air dive to 180 feet.

During a simulated O_2-He dive to 1500 feet Bennett and Gray[4] reported decreases in urinary sodium and calcium and increased excretion of potassium and inorganic phosphorus during compression. However, they reported no changes in blood minerals and electrolytes. On the other hand, Schaefer et al[19] observed increased urinary sodium as well as increased inorganic phosphorus during saturation-excursion dives to 1000 feet.

It has been suggested that electrolyte imbalance during hyperbaric exposure may result from hyperventilation and fluid shifts[19], increased corticosteroid and/or aldosterone production[4] or alterations in membrane permeability related to inert gas narcosis[3] and that these in turn are related to the incidence of symptoms of decompression sickness.

The purpose of this study has been to investigate the time course of possible latent shifts of minerals and electrolytes in blood and urine subsequent to hyperbaric exposure and severe decompression stress.

METHOD AND MATERIAL

Mature male rats of the Sprague-Dawley strain averaging 538 grams were pressurized and decompressed according to a schedule previously determined to afford a selected incidence of survival after severe decompression injury[10]. For the purpose of this paper, severe decompression is defined as that decompression which is neither explosive, resulting in 100% mortality, nor "completely safe", resulting in no apparent symptoms of bends. The schedule used here results in a mortality of approximately 33%. The survivors are then considered to have suffered severe decompression stress. Briefly, the schedule entails pressurization in air to 300 feet of sea water (FSW) at a rate of 60 feet/minute with a bottom stay of 25 minutes. Decompression is made in two stages: 300 FSW to 60 FSW

at a rate of 20 feet/minute with a stop at 60 FSW for 15 minutes and then to the surface at 4 feet/minute.

Upon reaching the surface, one group of surviving animals was placed in individual metabolism cages with food and water supplied ad lib. Twenty-four hour urine samples were collected for periods up to 5 days and acidified with concentrated HCl.

A second group of surviving animals was sacrificed at one hour, one day, two days, or three days post-dive. These animals were anesthetized with sodium pentobarbital and blood was withdrawn from the abdominal aorta by syringe which contained no anti-coagulant. The blood was immediately injected into Vacutainers® to maintain the anaerobic condition necessary for the determination of ionized calcium.

Following centrifugation the serum was removed from the Vacutainers anaerobically and the serum ionized calcium was determined using an Orion* specific ion flow-through electrode, Model 9920. Total calcium and inorganic phosphorus of serum and urine were determined using the Technicon** Autoanalyzer by the simultaneous micro-method N82 I/II. Serum and urinary sodium and potassium were measured in an Instrumentation Laboratory† Model 343 flame photometer while serum chlorides were determined by a Buchler-Cotlove†† chloridometer. The method of Hosley et al[8] was used for the determination of urinary hydroxyproline. Appropriate animals from the stock colony served as surface controls.

RESULTS

Blood electrolyte and mineral data from these studies are presented in Table 1. Of particular interest is the highly significant increase in ionized calcium within 1 hour after reaching the surface. This in turn is followed by a highly significant decrease in ionized calcium by the end of the first post-dive day. The ionized calcium remains significantly depressed throughout the remainder of the three-day post-dive study period. Although the control value is somewhat elevated when compared to human and guinea pig serum ionized calcium values[7, 15], it is consistent with those reported by Perris et al[13] for plasma from rats of the same age and weight as used in these studies.

Throughout the post-dive study the total calcium in the serum decreases

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Table 1. Effect of Severe Decompression Stress on Post-Dive Serum Minerals and Electrolytes of Adult Male Rats
Mean ±Standard Error of The Mean

	Ca++ mg/100ml	Ca mg/100ml	P mg/100ml	Na mEq/1	K mEq/1	CL mEq/1
Control						
X	6.02	10.20	6.27	141.1	4.46	99.29
SEM	.10	.07	.15	.3	.08	.30
N	35	32	35	33	33	31
1 Hour						
X	6.58	10.16	6.93	139.2	4.45	99.96
SEM	.12	.11	.34	.7	.13	.56
N	22	19	18	18	16	18
p	<.001		<.05	<.01		
1 Day						
X	5.66	10.02	6.09	139.1	4.58	98.84
SEM	.07	.09	.17	.7	.11	.80
N	28	25	27	28	28	19
p	<.01			<.01		
2 Days						
X	5.41	9.88	6.43	141.3	4.62	100.34
SEM	.10	.19	.30	.3	.71	.48
N	13	12	13	13	13	13
p	<.001					
3 Days						
X	5.44	9.94	7.04	140.1	4.49	99.78
SEM	.13	.11	.39	.9	.11	.48
N	15	15	15	15	14	15
p	<.005	<.05	<.025			

and becomes significantly lower by the third day, whereas the inorganic phosphorus, after a significant increase at one hour, returns toward control levels during the first two recovery days and rises significantly again at the end of three days.

Serum sodium becomes significantly lower after one hour post-dive and remains so through one day, after which the values return to control levels.

No changes are observed in serum potassium or chloride.

In Figures 1 and 2 are presented the data obtained from the analyses of the 24-hour urine collections. In terms of total excretion, for the first day after returning to the surface, all parameters studied were depressed below control levels. However, only the decrease in urinary sodium was significant. It might be noted here that

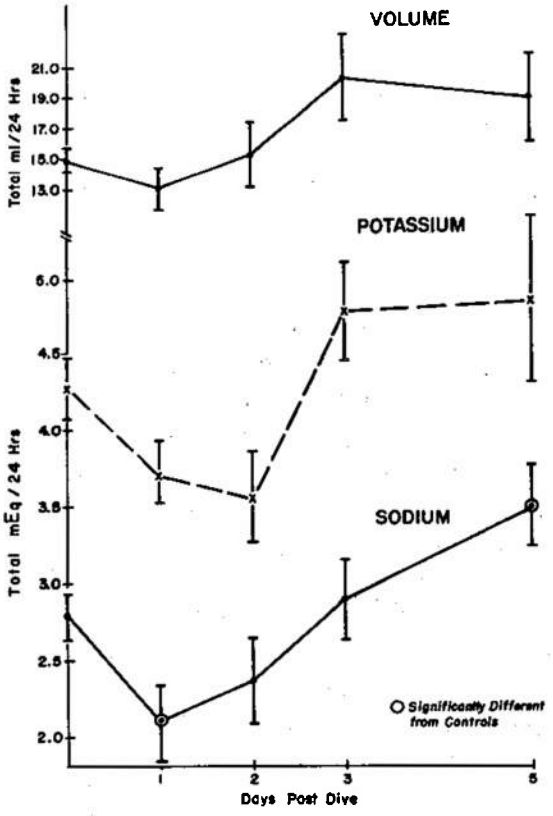

Fig. 1. Total urinary excretion/24 hours. Volume, sodium, and potassium excreted by adult rats following severe decompression stress. Mean ± SEM.

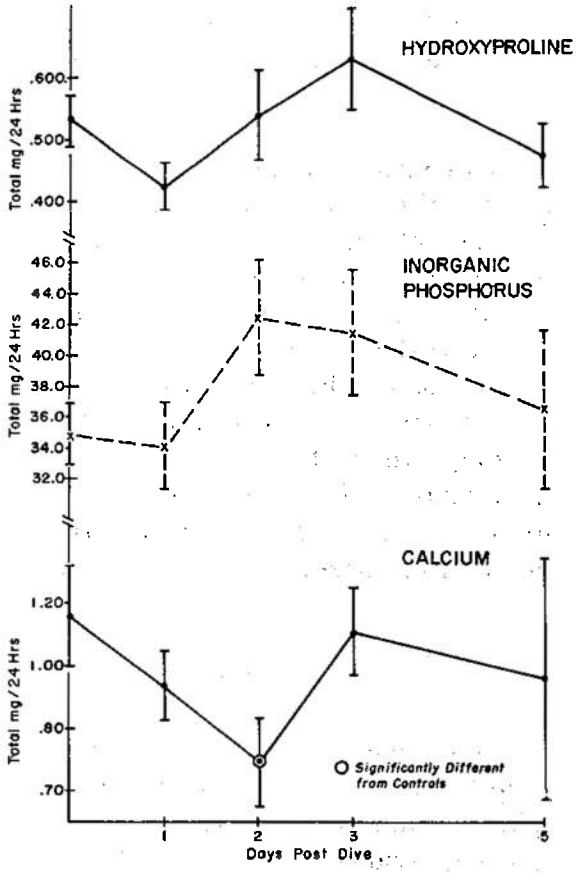

Fig. 2. Total urinary excretion/24 hours. Calcium, phosphorus, and hydroxyproline excreted by adult rats following severe decompression stress. Mean ± SEM.

for several hours after the dive, the animals were lethargic or comatose; many suffered respiratory distress, and some exhibited symptoms of limb twitching.

Urinary calcium excretion progressively decreased and became significantly lower than control levels after two days. By the third day, there appeared a general rebound response which sent excretion levels above those of the control. By approximately the fifth day, all values had returned to essentially control levels, except for sodium excretion which continued to rise.

Hydroxyproline excretion, although not significantly changed in these studies, also follows the pattern of decrease on the first post-dive day followed by an increase by the third day. By the fifth day, this excretion, like that of the calcium, has fallen somewhat below the control levels. The means, standard errors of the mean, number of observations and p values for the urinary parameters are presented in Appendix 1.

DISCUSSION

Using leucocyte measurements, Jacey et al[9], whose dive profile is identical with that used in this study, concluded that the response encountered one hour after severe decompression from a hyperbaric environment can be characterized as a general alarm reaction resulting from adrenal cortical stimulation.

Ogawa and Shibuta[11] using adrenalectomized rats showed a decrease in serum sodium as a result of glucocorticoid treatment. These authors also report a decrease in plasma volume and extracellular volume under the influence of glucocorticoids.

Human subjects suffering from acute decompression sickness have been reported to have large plasma volume deficits[2, 5, 6]. Jacey et al[9] also concluded that the hemoconcentration observed in their studies one hour after completion of the dive is indicative of plasma deficit. Since it is known that reduced plasma volume leads to increased ADH production[14], the one day post-decompression urinary retentions observed in these studies may be interpreted as resulting from an ADH mediated response to a decrease in plasma volume.

The occurrence of strong adrenal cortical stimulation might suggest the possibility that other cortical hormones such as aldosterone could be released. Decreases in sodium and increases in potassium excretion would then be expected. An argument against this interpretation can be based on the fact that although sodium was retained in these animals there was no potassium diuresis. In fact urinary potassium also tended to be retained.

Thus the one hour post-dive serum and one day post-dive urine responses observed in these studies are interpreted to be the result of adrenal cortical stimulation; the former as a direct response to the cortical hormones,

the latter as a secondary response to the stress-mediated reduction in plasma volume.

The rationale for determining hydroxyproline in these studies lies in the premise that this material is a major component of the organic matrix of bone. Upon removal of the mineral components from bone, it follows that some dissolution of the organic material would occur and that hydroxyproline would be excreted. Indeed, this relationship between bone mineralization and hydroxyproline has been reported by Rassmussen and Pechet[17]. In addition, Wachman and Bernstein[20] relate negative mineral balance with increased hydroxyproline excretion during metabolic acidosis. Thus hydroxyproline may serve as a sensitive and easily determined indicator of the metabolic activity in bone, whereas measurement of calcium and/or phosphorus alone may be inconclusive inasmuch as they play multiple roles in the body. However, these studies produced no statistically significant changes in total hydroxyproline excretion and would thereby suggest that major bone metabolism and/or parathyroid hormone activity is probably not involved in these early mineral shifts. On the other hand, the trend toward decreased excretion of calcium might suggest a sequestering of this mineral in bone since it has been shown that approximately 99% of the body calcium is stored in bone[18, 21]. This idea is further supported by the observation that serum calcium also decreases throughout the study period. Further study will be required to ascertain the period of this suggested increase in bone mineralization, and its possible relationship to calcitonin activity, as well as its relationship to the development of dysbaric osteonecrosis, and to the decreases in bone density observed by Adams et al[1] immediately following decompression.

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Appendix I. Effect of Severe Decompression Stress on Post-Dive Urinary Excretion of Minerals, Electrolytes and Hydroxyproline of Adult Male Rats. Twenty-Four Hour Collections.
Mean ± Standard Error of the Mean

		Na		K		Ca		P		Hydroxyproline	
			Total		Total		Total		Total		Total
Control	Vol ml	mEq/l	mEq	mEq/l	mEq	mg/100ml	mg	mg/100ml	mg	µg/ml	mg
$\bar{X}$	14.9	187	2.80	286	4.28	7.25	1.16	233	34.9	36.86	.533
SEM	.8	8	.14	10	.20	.79	.16	9	2.0	1.85	.038
N	35	34	34	34	34	34	34	34	34	35	35
1 Day											
$\bar{X}$	13.0	181	2.10	324	3.70	8.24	.940	288	34.1	34.60	.422
SEM	1.4	18	.22	24	.24	.78	.110	24	2.85	2.00	.048
N	20	20	20	20	20	20	20	20	20	20	20
p			<.01					<.05			
2 Days											
$\bar{X}$	15.2	184	2.36	290	3.56	6.46	.744	322	42.4	40.99	.538
SEM	2.1	23	.28	21	.30	1.04	.087	23	3.7	4.02	.072
N	20	20	20	20	20	19	19	19	19	20	20
p							<.05	<.001			
3 Days											
$\bar{X}$	20.2	154	2.90	266	4.78	6.12	1.11	235	41.4	34.10	.627
SEM	2.8	11	.26	19	.33	.89	.14	16	4.1	2.90	.083
N	20	20	20	20	20	20	20	20	20	20	20
p		<.02									
5 Days											
$\bar{X}$	18.8	198	3.50	272	4.85	4.56	.960	199	36.4	25.86	.468
SEM	2.9	19	.27	31	.54	1.11	.381	11	5.1	2.98	.050
N	5	5	5	5	5	5	5	5	5	5	5
p			<.05					<.025		<.001	

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